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(54) Title: IMPROVEMENTS IN OR RELATING TO MACHINE VISION EQUIPMENT

(57) Abstract: A method of setting-up machine vision equipment is disclosed, which equipment comprises imaging means comprising a camera defining a field of view and being adapted to form an image of a test object within said field of view, and processing means for processing said image for determining one or more physical properties of said test object, and first supporting means for supporting a test object at a predetermined distance from said camera within said field of view; said method being characterised by: providing second supporting means for supporting at least one reference object; placing a reference object having at least one accurately known dimension on said second supporting means; selectively moving one or more of said camera, said first supporting means and said second supporting means, such that said reference object is brought into the camera's field of view at said predetermined distance from said camera; imaging said reference object to obtain at least one image, and processing said at least one image to determine the optimum configuration of the imaging means; and thereafter adjusting the configuration of said imaging means to said optimum configuration. Also disclosed is a dimensionally stable reference object having at least one accurately known dimension which is fabricated from a ceramic material having a low reflectance or albedo value. Preferably, the reference object comprises a cylindrical bar having an accurately known diameter. Said ceramic material may comprise a ceramic alumina.

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Improvements in or relating to machine vision equipment

The present invention provides improvements in or relating to machine vision equipment, and has particular reference to a method and apparatus for automatically setting-up such machine vision equipment.

5 Co-pending international patent application no. PCT/GB2004/xxxxxx [*attorney reference JRJC/41823*], corresponding to earlier United Kingdom application no. 0306468.0, the contents of which international application are fully incorporated herein by reference, discloses a method and apparatus for determining one or more physical properties of a rolled smoking article or filter rod, comprising positioning a rolled smoking
10 article or filter rod within a field of view, illuminating the field of view, imaging the rolled smoking article or filter rod within the field of view to form an image, and analysing the image to determine one or more physical properties of the rolled smoking article or filter rod. Typically, the image is a digital image which is acquired using a digital camera, preferably a digital video camera. The image may be acquired using any wavelength or
15 range of wavelengths, for example infrared light. Thus, the image comprises a digital array of pixels which may be analysed using suitable processing means to determine one or physical properties of the rolled smoking article or filter rod such as its length, diameter, ovality, and the like.

As described in co-pending PCT/GB2004/xxxxxx [*attorney reference*
20 *JRJC/41823*], analysis of the digital image may be performed using well-known algorithms to detect edges within the image.

Such algorithms may employ contrast levels for defining a point at which an edge is defined as being present, the length (in pixels) along a detected edge being used to determine a contiguous and true edge, and algorithms for carrying out statistical
25 probability calculations to confirm that a detected edge is a true edge. A preferred technique for detecting an edge within an image comprises generating horizontal and vertical region projections within a region of interest of the image, and then analysing the projections in order to detect any significant edges. Such image processing techniques are not described further herein, but are described in a number of standard reference works
30 including Sonka, *et al.*, 1999, *Image Processing, Analysis and Machine Vision*, 2nd Edition, page 356 (6.35), Pacific Grove: PWS Publishing, ISBN 0-534-95393-X, the contents of which are incorporated herein by reference.

The accurate detection of edges within a digital image by imaging processing techniques of the kind described above relies on such edges being sharply in focus within the image, to allow the edges to be detected without undue exposure of the image which might lead to undesirable affects such as "blooming", which is associated with many digital imaging devices, particularly those comprising CCD-type sensors.

The machine vision equipment is also required to be calibrated to provide accurate conversion of distances measured in pixels in the image to actual distances measured, for example, in millimetres or inches.

Calibration of machine vision equipment is typically carried out using reference objects of accurately known dimensions. A known reference object comprises a machined solid steel cylinder having an accurately known diameter. Steel reference objects are used in view of their good dimensional stability. However, metal reference objects are not suitable for calibrating machine vision equipment of the kind described by co-pending PCT/GB2004/xxxxxx [*attorney reference JRJC/41823*] in view of the high reflectance of the metal.

Furthermore, it is generally inconvenient manually to place a reference object in the field of view of the machine vision equipment for intermittent calibration and re-calibration.

There is therefore a need for a dimensionally stable reference object which is suitable for use for calibrating machine vision equipment of the kind disclosed by co-pending PCT/GB2004/xxxxxx [*attorney reference JRJC/41823*].

There is also a requirement for a method of automatically setting-up such machine vision equipment.

In accordance with one aspect of the invention therefore there is provided a dimensionally stable reference object having at least one accurately known dimension which is fabricated from a ceramic material having a low reflectance or albedo value. Preferably, the reference object comprises a cylindrical bar having an accurately known diameter.

Said ceramic material may comprise a ceramic alumina. Preferably, the ceramic material has an alumina content of more than about 70% by weight, and more preferably more than about 90% or 95% by weight. The ceramic material should be substantially impervious and should have good refractory properties, for example, refractoriness up to about 1700°C. Apart from alumina, the ceramic material may comprise various other

ceramic constituents, particularly magnesium oxide. In some embodiments, the ceramic material comprise about 99.7% weight alumina, with the balance being substantially magnesium oxide. A suitable ceramic material available commercially from W Haldenwanger Technishe Keramik GmbH & Co KG, Germany, under the trade mark "Alsint 99,7".

In another aspect of the present invention there is provided machine vision equipment incorporating automatic set-up means; said equipment comprising:

imaging means comprising a camera defining a field of view and being adapted to form an image of test object within said field of view, and processing means for processing said image for determining one or more physical properties of said test object; and

first supporting means for supporting a test object within said field of view at a predetermined distance from said camera;

characterised by:

second supporting means for supporting a reference object having a least one accurately known dimension;

moving means for selectively moving one or more of the camera, the first supporting means, and the second supporting means such that a reference object placed on the second supporting means is disposed within the camera's field of view at said predetermined distance from said camera;

adjusting means for automatically adjusting the configuration of the imaging means;

optimum configuration determining means for determining the optimum configuration of said imaging means by processing one or more images of a reference object placed on a the second supporting means; and

controlling means for controlling operation of the moving means, imaging means, adjusting means and optimum configuration determining means for bringing a reference object supported by said second supporting means into the camera's field of view, imaging said reference object, determining the optimum configuration of the imaging means, and adjusting the imaging means to said optimum configuration.

In yet another aspect of the present invention there is provided a method of setting-up machine vision equipment, said equipment comprising imaging means comprising a camera defining a field of view and being adapted to form an image of a test object within said field of view, and processing means for processing said image for determining one of

more physical properties of said test object, and first supporting means for supporting a test object at a predetermined distance from the camera within the field of view;

said method being characterised by:

providing second supporting means for supporting at least one reference object;

5 placing a reference object having at least one accurately known dimension on said second supporting means;

selectively moving one or more of the camera, the first supporting means and the second supporting means, such that said reference object is brought into the camera's field of view at said predetermined distance from the camera;

10 imaging the reference object to obtain at least one image, and processing said at least one image to determine the optimum configuration of the imaging means;

and thereafter adjusting the configuration of the imaging means to said optimum configuration.

In accordance with the present invention therefore, a reference object having at
15 least one accurately known dimension may be placed on the second supporting means, and when the machine vision equipment is required to be set-up, or the set-up of machine vision equipment is required to be checked, the controlling means cause the reference object on the second supporting means to be brought into the camera's field of view at the
20 same predetermined distance from the camera as a test object on the first supporting means during normal operation of the machine vision equipment. The reference object is then imaged, and the image is processed to determine the optimum set-up of the imaging means; the imaging means are then adjusted to said optimum set-up. The reference object may then be removed from the camera's field of view and replaced by said first supporting means for use or continued use of the machine vision equipment for determining one or
25 more physical properties of a test object.

In some embodiments, said optimum configuration determining means may be adapted for determining the optimum configuration of the imaging means by processing a plurality of images of said reference object obtained with said imaging means in different respective configurations, and said controlling means may be adapted to control said
30 imaging means, adjusting means, and optimum configuration determining means to obtain and process serial images of said reference object whilst adjusting progressively the configuration of the imaging means, and to determine the optimum configuration on the basis of said serial images.

Thus, as disclosed in co-pending PCT/GB2004/xxxxxx [*attorney reference JRJC/41823*], the camera may comprise means for automatically adjusting the focal length of the camera. For example, the camera may comprise a barrel portion housing a lens, and said barrel portion may be provided with a gear which is adapted to be driven by a toothed belt from a DC motor controlled by said controlling means. As described above, it is important, when measuring dimensions of a test object by analysing a digital image of the test object to detect the presence of significant edges, to ensure that the image of the test object is properly in focus. Thus, in accordance with the present invention, the optimum configuration determining means may comprise optimum focal length determining means, and said controlling means may be adapted for controlling the adjusting means, imaging means and optimum focal length determining means to obtain and process serial images of the reference object at different respective focal lengths, and to determine the optimum focal length at which the reference object is best in focus, and for controlling the adjusting means thereafter to adjust the focal length of the camera to said optimum focal length.

The second supporting means are preferably configured to support a reference object having substantially the same shape and size in substantially the same orientation in the field of view as the test object. Where the test object comprises a rolled smoking article or filter rod, the reference object suitably comprises a cylindrical bar having substantially the same diameter as the rolled smoking article or filter rod. In order to measure the diameter of a rolled smoking article or filter rod, a digital image of the rolled smoking article or filter rod is analysed to detect opposite, substantially parallel edges of a profile of the rolled smoking article or filter rod in the image, which profile corresponds to a cross-section through the rolled smoking article or filter rod through its central axis. Thus, in order to ensure that said opposite edges are properly focused in the image, the camera should be focused on the centre axis of the rolled smoking article or filter rod. Preferably, therefore the second supporting means are configured to support a cylindrical reference bar in an orientation substantially orthogonal to the optical axis of the camera.

Preferably the camera comprises a digital camera which is adapted to form the image as a regular array of pixels.

In some embodiments, said configuration determining means may comprise calibration determining means adapted to compare an actual measured value of said at least one dimension of said reference object with said accurately known value; said adjusting means may be adapted for adjusting the calibration of said imaging means; said controlling

means may be configured for controlling said imaging means, calibration determining means, and adjusting means, for measuring said at least one dimension of said reference object to obtain a measured value, comparing said measured value with the accurately known value, and adjusting the calibration of the imaging means accordingly, such that the measured value equals the known value. In this way, the controlling means may generate a calibrated conversion factor for converting distances in the image of a test object, measured in pixels, to actual distances, measured in, for example, millimetres or inches.

Those skilled in the art will know that diameter measurements using machine vision equipment may be sensitive to optical effects associated with the camera.

Accordingly, a calibration curve of actual length *versus* pixels may be non-linear. Accordingly, it is desirable to calibrate the machine vision equipment at least two different known diameters, and then to interpolate between those known diameters to establish a calibrated scale.

Thus, in accordance with a particular aspect of the present invention said second supporting means may be adapted to support a plurality of reference objects, each having substantially the same shape as the test object, but each having a different respective, accurately known value of said at least one dimension; said moving means may be adapted for selectively moving said one or more of the camera, first supporting means and second supporting means to bring each reference object in turn into the camera's field of view at the predetermined distance from the camera; said calibration determining means may be adapted for comparing the measured value of said at least one dimension of each reference object with the respectively accurately known value, and to generate a calibration curve for said imaging means on the basis of said comparisons.

In some embodiments, said second supporting means may be adapted to support three reference objects. As described above, each reference object may comprise a cylindrical bar of accurately known diameter.

The reference objects may be interchangeable in order to calibrate the machine vision system for dimension measurements within different ranges. By supporting three reference objects the second supporting means may be adapted, for any given measurement range, to support reference objects having accurately known dimensions respectively at or towards each end of the measurement range and at an arbitrary dimension intermediate said two ends, for example substantially towards the middle of the measurement range.

Thus, the provision of five reference objects allows the machine vision equipment in accordance with the present invention to be calibrated with three-point calibration for use in three different, but overlapping, measurement ranges.

Conveniently, said second supporting means may comprise at least one holder for holding each reference object, each holder defining a v-shaped cavity which is configured to receive transversely the cylindrical reference bar at the same depth into the cavity regardless of the diameter of the bar. In some embodiments, said second supporting means may comprise two holders for holding each reference object, one holder at or towards each end of the respective bar. In this way, each reference object can easily be positioned at said predetermined distance from the camera, irrespective of the diameter of the reference object. It will be appreciated that by placing each reference object on the second supporting means at the same predetermined distance from the camera, the central axes of the reference objects will be positioned at different respective distances from the camera. However, the actual differences in diameter between the reference objects will be small, and within the allowed tolerance of the focus of the camera. Accordingly, there is no need in practice to re-adjust the focal length of the camera for imaging and calibrating against each reference object.

The present invention therefore provides improvements in or relating to machine vision equipment, particularly equipment of the kind described by co-pending PCT/GB2004/xxxxxx [*attorney reference JRJC/41823*], by providing a method and apparatus for automatically setting-up the machine vision equipment; in particular to set-up automatically the focal length and calibration of the machine vision equipment. The present invention also provides a suitable ceramic reference object for use in the automatic setting-up method of the present invention.

Following is a description by way of example only with reference to the accompanying drawings of embodiments of the present invention:

In the drawings:

FIG. 1 is a schematic side view of machine vision equipment in accordance with the present invention.

FIG. 2 is a schematic end view of machine vision equipment in accordance with the present invention.

FIG. 3 is graph which shows an illustrative, non-linear relationship between pixels and actual distance for a digital camera.

Co-pending international patent application no. PCT/GB2004/xxxxxx [*attorney reference JRJC/41823*] discloses machine vision equipment for measuring one or more physical properties of a rolled smoking article or filter rod such, for example, as a cigarette
10. As described above, the present invention relates to improvements in or relating to such
5 machine vision equipment, and accordingly, full details of the construction and operation of the machine vision equipment are not repeated herein; the following describes the machine vision equipment only to the extent that is necessary to describe the improvements provided by the present invention.

Thus, as described in PCT/GB2004/xxxxxx [*attorney reference JRJC/41823*],
10 machine vision equipment comprises a vision system 200 comprising a digital near infra-red video camera 222 and having a barrel portion 224 accommodating a lens (not shown) which defines a first optical axis 230. The vision system 200 is connected to a suitable computer control system (not shown) which includes a frame-grabber device adapted to receive and capture and video signal from the camera 222. The barrel portion 224 is
15 formed with a gear (not shown) which is drivable by a DC motor for automatically adjusting the focal length of the camera 222.

In accordance with the present invention, said camera 222 is mounted on a carriage 400 which comprises two substantially parallel, depending slides 402, 403 which are adapted to engage respective spaced parallel rods 404, 405, to allow horizontal
20 translational movement of the carriage 400 in a direction substantially orthogonally to said first optical axis 230.

Spaced from the camera 222, the carriage 400 carries an upstanding piece 211 of generally triangular cross-section having an inclined face 212. Said inclined face 212 is aligned with the first optical axis 230, and subtends an angle of about 45° thereto in a
25 vertical plane, and is oriented substantially orthogonally to the first optical axis 230 in a horizontal plane; said inclined face 212 carries a planar mirror 214 for reflecting light on said first optical axis 230 through 90° to a second substantially vertical optical axis 260.

Juxtaposed said upstanding piece 211, the carriage 400 includes a mounting block 410 which is fixedly secured, as best shown in FIG. 2, to a belt drive 412 for driving the
30 carriage 400 translationally along said rods 404, 405.

The belt drive 412 comprises an endless belt 413 which extends around two spaced rollers for 415, 416. Said belt drive 412 is connected to a selectively operable servo-motor (not shown) under the control of said computer control system.

With reference to FIG. 2, said carriage 400 further comprises a bracket 230 in the form of an elongated C having a substantially horizontal upper portion 234 and defining a recess 231 which is open at one end 233 substantially in line with said second optical axis 260. On its underside, the upper portion 234 carries an infra-red back-light 252 which is selectively operable to produce a 3mm wide collimated beam. Said back-light 252 is substantially aligned at the second optical axis 260.

Within said recess 231, at said open end 233, the bracket 230 supports a substantially horizontal, generally planar jig member 240 having an aperture 242 formed therein in alignment with the second optical axis 260. Being fixedly secured to the bracket 230, the jig member 240 is moveable with the carriage 400, and carries two laterally spaced diffuse infra-red side-lights 254 which are positioned respectively on opposite sides of the aperture 242, obliquely of the second optical axis 260. The infra-red back-light 252 and infra-red side-lights 254 are connected to a power control box (not shown) which is adapted to receive control signals from said frame-grabber. Said side-lights 254 can be actuated independently of said back-light 252, and serve to illuminate an object space 250 defined by the upper portion 234 of the brackets 230 and the jig member 240 with diffuse infra-red light.

Circumjacent to the back-light 252, the underside of said upper portion 234 forms a background for the object space 250 and is uniformly dark to give good contrast with an object to be imaged within said object space 250.

Fixedly secured above the carriage 400 are two opposing pairs of rollers 310, 311; 312 forming part of a transport system for a rolled smoking article or filter rod 10 to be imaged using the vision system 200. Each pair of rollers 310, 311; 312 comprises two juxtaposed rollers which define a respective upper, generally V-shaped groove 314 at substantially the same level as the jig member 240. The rollers 310, 311; 312 are oriented substantially parallelly to the first optical axis 230, substantially orthogonally to the direction of movement of the carriage 400, and are positioned on opposite sides of the jig member 240, with their respective V-shaped grooves 314 in alignment.

The rollers 310, 311; 312 are configured to support slidably a rolled smoking article or filter rod, such as cigarette 10 as shown in FIGS. 1 and 2. The transport system comprises a pusher (not shown) for pushing the cigarette 10 axially along the V-shaped grooves 314 defined by the respective pairs of rollers 310, 311; 312, and the rollers and jig member 240 are positioned so that the cigarette can be transferred smoothly from one pair

of rollers **310, 311** to the other pair **312** via the jig member **240**. The rollers **310-312** are connected to the computer control system and are adapted to rotate about their respective axes as shown in FIG. 1 so as to rotate the cigarette **10** about its longitudinal axis **16** for reasons described in co-pending PCT/GB2004/xxxxxx [attorney reference JRJC/41823].

5 The rollers **310-312** are further configured and arranged so as to define a clearance between each pair of rollers **310, 311; 312** and the respective side of the jig member **240**, so that upon operation of the belt drive **412**, the jig member **240** can be withdrawn from the space between the two opposing pairs of rollers **310, 311; 312** without interference and, upon reversal of the belt drive **412**, re-inserted into that space.

10 Mounted within said recess **231** is a fixed plate **420** which is generally U-shaped in plan view. Said U-shaped plate **420** comprises two arms, one of which **422** is shown in FIG. 2. Each arm **420** carries on its upper surface a plurality of generally V-shaped holder members **423**. Each holder member **423** on one arm **422** is aligned with a corresponding holder member **423** on the other arm of the U-shaped plate **420**. In the embodiment shown
15 in FIG. 2, each arm **422** supports three holder members **423**.

The U-shaped plate **420** is positioned such that when the belt drive **412** is operated to move the carriage **400**, the second optical axis **260** of the camera **222** traverses the space between the two arms **422** of the new-shaped plate **420**.

20 The pairs of holders members **423** are adapted for releasably supporting respective reference objects **430** of different respective sizes.

Each reference object **430** is fabricated from a highly dimensionally stable alumina ceramic material, and has a precisely machined cylindrical shape having an accurately known respective diameter. In FIG. 2, the three reference objects **430** are of three different sizes, namely relatively small, relatively large and intermediate. For the sake of illustration,
25 the differences in size between the reference object **430** have been greatly exaggerated in FIG. 2. In practice, the diameters of the reference object **430** are selected to provide three calibration points for calibrating the vision system **200** as described in more detail below. The diameters are chosen to provide calibration points at the upper and lower extremities and substantially in the middle of the expected range of measured diameters of the
30 cigarette **10**. Five different reference objects **430** may be provided having the following diameters:

4.9mm +/- 0.0025mm

5.75mm +/- 0.00025mm

6.6mm +/-0.00025mm

7.45mm +/-0.00025mm

8.3mm +/- 0.00025mm

5 By selecting any three successive objects 430 from the above, the five objects can be used to provide three-point calibration across three different measurement ranges as described below.

10 A preferred material for making the cylindrical reference objects 430 is "Alsint 99, 7" which is commercially available from W Haldenwanger Technishe Keramik GmbH & Co KG, Germany, and comprises about 99.7% wt. alumina, with the remainder being mainly magnesium oxide.

15 As best shown in FIG. 2, a cigarette 10 supported by the juxtaposed rollers 310-312 will sit in the respective grooves 314 at a predetermined height above the mirror 214 and thus at a predetermined optical distance from the camera 222. The distance of the central axis 16 of the cigarette 10 from the camera 222 will vary depending on the diameter of the cigarette 10. In order to calibrate the vision system 200 accurately, it is desirable that the reference objects 430 should be positioned accurately at the same distance from the camera 222. Accordingly, the V-shaped holders 423 are shaped to replicate the shape of the grooves 314 in the respective pairs of rollers 310, 311; 312, such that a reference object 430 of any of the aforementioned diameters will sit in the V-shaped recess 424 defined by the holders 423 at the same height above the mirror 214.

20 The operation of the machine vision equipment in accordance with the present invention is now described.

25 The vision system 200 of the equipment is adapted to form a digital image of the profile of a rolled smoking article or filter rod, such as a cigarette 10, supported by the rollers 310-312 and jig member 240. As the cigarette 10 is pushed slidingly along the grooves 314, the part of the cigarette 10 that is imaged is the part that is visible through the aperture 342 formed in the jig member 240. The video output from the camera 222 is sampled by the frame-grabber and processed by the computer control system in accordance with standard vision block techniques. The side lights 254 are actuated as required to light the cigarette 10 with diffuse light against the uniformly dark background formed on the underside of the upper portion 234 of the bracket 230. The shutter speed of the camera 222 is adjusted to provide good contrast between the cigarette 10 and the dark background, without undue exposure which might give rise to unwanted "blooming" phenomena.

Preferably, the video camera is operated in field mode, with its major axis oriented substantially orthogonally to the minor axis of the cigarette 10 to take advantage of the full resolution of the camera.

5 In order to measure the diameter (d) of the cigarette 10, for example, an image of the profile of the cigarette 10 is processed by the computer control system to detect in the image the two parallel, opposite edges of the profile. As described above, suitable imaging software may be run on the computer control system for analysing the image using well known algorithms for detecting edges. Such algorithms typically comprehend measuring contrast levels for defining a point at which an edge is defined as being present, the length
10 in pixels along the defined edge being used to determine a contiguous and true edge, and involve statistical considerations to determine the probability that a detected edge is a true edge. An edge may be detected by analysing horizontal and vertical region projections of the image as described, for example, by Sonka, *et al.*, 1999 *Image Processing, Analysis and Machine Vision, 2nd Edition*, page 256 (6.35), Pacific Grove: PWS Publishing, ISBN
15 0-534-95393-X, the contents of which are incorporated herein by reference.

In order to provide an accurate measurement of distance such, for example, as diameter (d) it is necessary for the camera 222 to be properly focused on the test object in the object space 250, and for the vision system 200 to be properly calibrated to convert pixel distances into actual distances.

20 Thus in order to set-up the machine vision equipment in accordance with the present invention, the computer control system actuates the belt drive 412 to move the carriage 400 translationally such that the second optical axis 260 is positioned directly in alignment with one of the reference objects 430 supported by the V-shaped holder members 423. Part of the selected reference object 430 is visible to the camera 222 through
25 the space between the two arms 422 of the U-shaped plate 420 and the aperture 242. For auto-focusing the camera 222, it is preferred to use the middle reference object 430. Under control of the computer control system the focal length of the camera 222 is then adjusted progressively using the DC motor to drive the gear formed in the barrel portion 224 of the camera 222, and the image of the reference object 430 is serially sampled to form a series
30 of image samples. The image samples are then analysed by the computer control system using the image analysis algorithms of the kind referred to above to determine the image sample, and thus position of the barrel portion 224 of the camera 222, in which the edges of the profile of the reference object 430 in the image are best in focus. Having established

the correct focal length of the camera 222 the DC motor is operated again to return the barrel portion 224 to the correct in-focus position.

All three reference objects 430 are then used to calibrate the vision system 200, by imaging each of the three reference objects 430 in turn. Thus, the belt drive 412 is operated to move the carriage 400 such that one of the end-most reference objects 430 is visible to the camera 222. With the camera 222 focused as mentioned above, the image of the profile of the reference object 430 which is visible through the U-shaped plate 420 and aperture 242 is sampled by the frame-grabber, and the image sample is processed to detect the two straight, opposite edges of the profile. The distance between the two straight edges is equal to the diameter of the reference object 430.

It will be appreciated that the profile of each reference object corresponds to a cross-section of the reference object 430 through its central axis 16. The vision system 200 is also focused, as described above, on the central axis 16 of the middle reference object 430, and for the reasons described above, the central axes 16 of the other two referenced objects are disposed at slightly different optical distances from the camera 222 from the distance of the central axis of the middle reference object 430. However, these differences in distance are within the tolerance of the focus of the camera 222, and it is not necessary to re-focus the camera 222 on each different reference object 430.

Having measured the diameter of the one end-most reference object 430, the belt drive 412 is then operated to bring the camera 222 into alignment with the middle reference object 430, and its diameter is measured. Finally, the diameter of the other end-most reference object 430 is determined as described above.

Since the respective diameters of the three reference objects 430 are accurately known, the measured diameters can be used to generate a three-point calibration curve as shown in FIG. 3 which is non-linear owing to well-known visual effects associated with digital cameras. As described above, combinations of three sequential reference objects 430 selected from five different reference objects can be used to provide three point calibrations across three different measurement ranges. In FIG. 3, these three ranges are represented by the symbols \circ , \bigcirc and \dagger .

The calibration curve generated by the computer control system is stored in the computers memory, and the belt drive 412 is then returned to its start position such that the jig member 240 is disposed in the space interposing the opposing ends of the pairs of rollers 310, 311; 312 as described above. The machine vision equipment in accordance

with the present invention is then set-up to measure one or more physical properties, particularly the dimensions, including diameters, of test objects in the object space 250 carried by the rollers 310, 311; 312 in accordance with co-pending PCT/GB2004/xxxxxx [attorney reference JRJC/41823].

5 In case the focus or calibration of the vision system 200 should drift during use, the control system may be programmed to interrupt testing of test objects intermittently and to re-focus and re-calibrate the vision system 200 as described above.

10 The present invention thus provides improvements in or relating to machine vision equipment of the kind described in co-pending PCT/GB2004/xxxxxx [attorney reference JRJC/41823] by providing automated setting-up of the cameras 222 focus and calibration of the vision system using a plurality of reference objects in the form of accurately fabricated ceramic cylindrical bars.

Claims

1 Machine vision equipment incorporating automatic set-up means; said equipment comprising:

5 imaging means comprising a camera defining a field of view and being adapted to form an image of a test object within said field of view, and processing means for processing said image for determining one or more physical properties of said test object;

first supporting means for supporting a test object within said field of view at a predetermined distance from said camera;

characterised by:

10 second supporting means for supporting a reference object having at least one accurately known dimension;

moving means for selectively moving one or more of the camera, the first supporting means, and the second supporting means such that a reference object placed on the second supporting means is disposed within the camera's field of view at said
15 predetermined distance from said camera;

adjusting means for automatically adjusting the configuration of the imaging means;

optimum configuration determining means for determining the optimum configuration of said imaging means by processing one or more images of a reference
20 object placed on the second supporting means; and

controlling means for controlling operation of said moving means, imaging means, adjusting means, and optimum configuration determining means for bringing a reference object supported by said second supporting means into the camera's field of view, imaging said reference object, determining the optimum configuration of the imaging means, and
25 adjusting the imaging means to said optimum configuration.

2 Machine vision equipment as claimed in claim 1, characterised in that said optimum configuration determining means are adapted for determining the optimum configuration of the imaging means by processing a plurality of images of said reference object obtained with said imaging means in different respective configurations, and said
30 controlling means are adapted to control said imaging means, adjusting means, and optimum configuration determining means to obtain and process serial images of said reference object means whilst adjusting progressively the configuration of the imaging means, and to determine the optimum configuration on the basis of said serial images.

3 Machine vision equipment as claimed in claim 2, characterised in that said
adjusting means are adapted for adjusting the focal length of the camera, said optimum
configuration determining means comprise optimum focal length determining means, and
said controlling means are adapted for controlling the adjusting means, imaging means,
5 and optimum focal length determining means to obtain and process serial images of the
reference object at different respective focal lengths, and to determine the optimum focal
length at which the reference object is best in focus, and for controlling the adjusting
means thereafter to adjust the focal length of the camera to said optimum focal length.

4 Machine vision equipment as claimed in claim 1, claim 2, or claim 3, characterised
10 in that said second supporting means are configured to support a reference object having
substantially the same shape and size in substantially the same orientation in said field of
view as the test object.

5 Machine vision equipment as claimed in any preceding claim, characterised in that
said camera comprises a digital camera which is adapted form said image as a regular array
15 of pixels.

6 Machine vision equipment as claimed in claim 5, characterised in that said
configuration determining means comprise calibration determining means adapted to
compare an actual measured value of said at least one dimension of said reference object
with said accurately known value, said adjusting means are adapted for adjusting the
20 calibration of said imaging means, and said controlling means are configured for
controlling said imaging means, calibration determining means and adjusting means for
measuring said at least one dimension of said reference object to obtain a measured value,
comparing said measured value with the accurately known value, and adjusting the
calibration of the imaging means accordingly such that the measured value equals the
25 known value.

7 Machine vision equipment as claimed in claim 6, characterised in that said second
supporting means are adapted to support a plurality of reference objects, each having
substantially the same shape as the test object, but each having a different respective,
accurately known value of said at least one dimension, said moving means are adapted for
30 selectively moving one or more of the camera, first supporting means and second
supporting means to bring each reference object in turn into the camera's field of view at
the said predetermined distance from the camera; and said calibration determining means
are adapted for comparing the measured value of said at least one dimension of each

reference object with the respective accurately known value, and to generate a calibration curve for said imaging means on the basis of said comparisons.

8 Machine vision equipment as claimed in claim 7, wherein said second supporting means is adapted to support three or more reference objects.

5 9 Machine vision equipment as claimed in claim 8, wherein each reference object comprises a cylindrical bar of accurately known diameter.

10 10 Machine vision equipment as claimed in claim 9, characterised in that said second supporting means comprises at least one holder for holding each reference object, each holder defining a V-shaped cavity which is configured to receive transversely a cylindrical reference bar at the same depth into the cavity regardless of the diameter of the bar.

11 Machine vision equipment as claimed in claim 10, wherein said second supporting means comprises two holders for holding each reference object, one holder at or towards each end of the respective bar.

15 12 A method of setting-up machine vision equipment, which equipment comprises imaging means comprising a camera defining a field of view and being adapted to form an image of a test object within said field of view, and processing means for processing said image for determining one or more physical properties of said test object, and first supporting means for supporting a test object at a predetermined distance from said camera within said field of view; said method being characterised by:

20 providing second supporting means for supporting at least one reference object;

placing a reference object having at least one accurately known dimension on said second supporting means;

25 selectively moving one or more of said camera, said first supporting means and said second supporting means, such that said reference object is brought into the camera's field of view at said predetermined distance from said camera;

imaging said reference object to obtain at least one image, and processing said at least one image to determine the optimum configuration of the imaging means;

and thereafter adjusting the configuration of said imaging means to said optimum configuration.

30 13 A method as claimed in claim 12, characterised by obtaining and processing a series of images of said reference object whilst adjusting progressively the configuration of the imaging means, and determining the optimum configuration on the basis of said series of images.

14 A method as claimed in claim 13, characterised by adjusting the focal length of the camera while obtaining and processing serial images of the reference object to determine the optimum focal length at which the reference object is best in focus; and thereafter adjusting the focal length of the camera to said optimum focal length.

5 15 A method as claimed in claim 14, characterised by placing on said second supporting means a reference object having substantially the same shape and size in substantially the same orientation in said field of view as the test object.

16 A method as claimed in any of claims 12 to 15, characterised in that said camera comprises a digital camera which is adapted form said image as a regular array of pixels.

10 17 A method as claimed in any of claims 12 to 16, characterised by obtaining an image of said reference object and measuring said at least one dimension, comparing the measured value of said dimension with the accurately known value, and thereafter adjusting the calibration of the imaging means such that the measured value substantially equals the known value.

15 18 A method as claimed in claim 17, characterised by supporting a plurality of reference objects on said second supporting means, each reference object having substantially the same shape as the test object, but each having a different respective, accurately known value of said at least one dimension, selectively moving one or more of the camera, first supporting means and second supporting means to bring each reference
20 object in turn into the camera's field of view at the said predetermined distance from the camera, comparing the measured value of said at least one dimension of each reference object with the respective accurately known value, and generating a calibration curve for said imaging means on the basis of said comparisons.

25 19 A method as claimed in claim 18, characterised by supporting three reference objects on the second supporting means, and imaging those reference objects to produce a calibration curve based on three points.

20 A method as claimed in claim 19, wherein each reference object comprises a cylindrical bar of accurately known diameter.

30 21 A method as claimed in claim 20 characterised by supporting each reference object on least one respective holder, said holder defining a V-shaped cavity which is configured to receive a transverse cylindrical reference bar at the same depth into the cavity regardless of the diameter of the bar.

22 A method as claimed in 21, wherein said second supporting means comprises two holders for holding each reference object, one holder at or towards each end of the respective bar.

23 A dimensionally stable reference object having at least one accurately known
5 dimension which is fabricated from a ceramic material having a low reflectance or albedo value.

24 A reference object as claimed in claim 23, wherein the reference object comprises a cylindrical bar having an accurately known diameter.

25 A reference object as claimed in claim 24 or claim 25, wherein the ceramic material
10 is substantially impervious and has good refractory properties.

26 A reference object as claimed in claim 23, claim 24, or claim 25, characterised in that said ceramic material comprises a ceramic alumina.

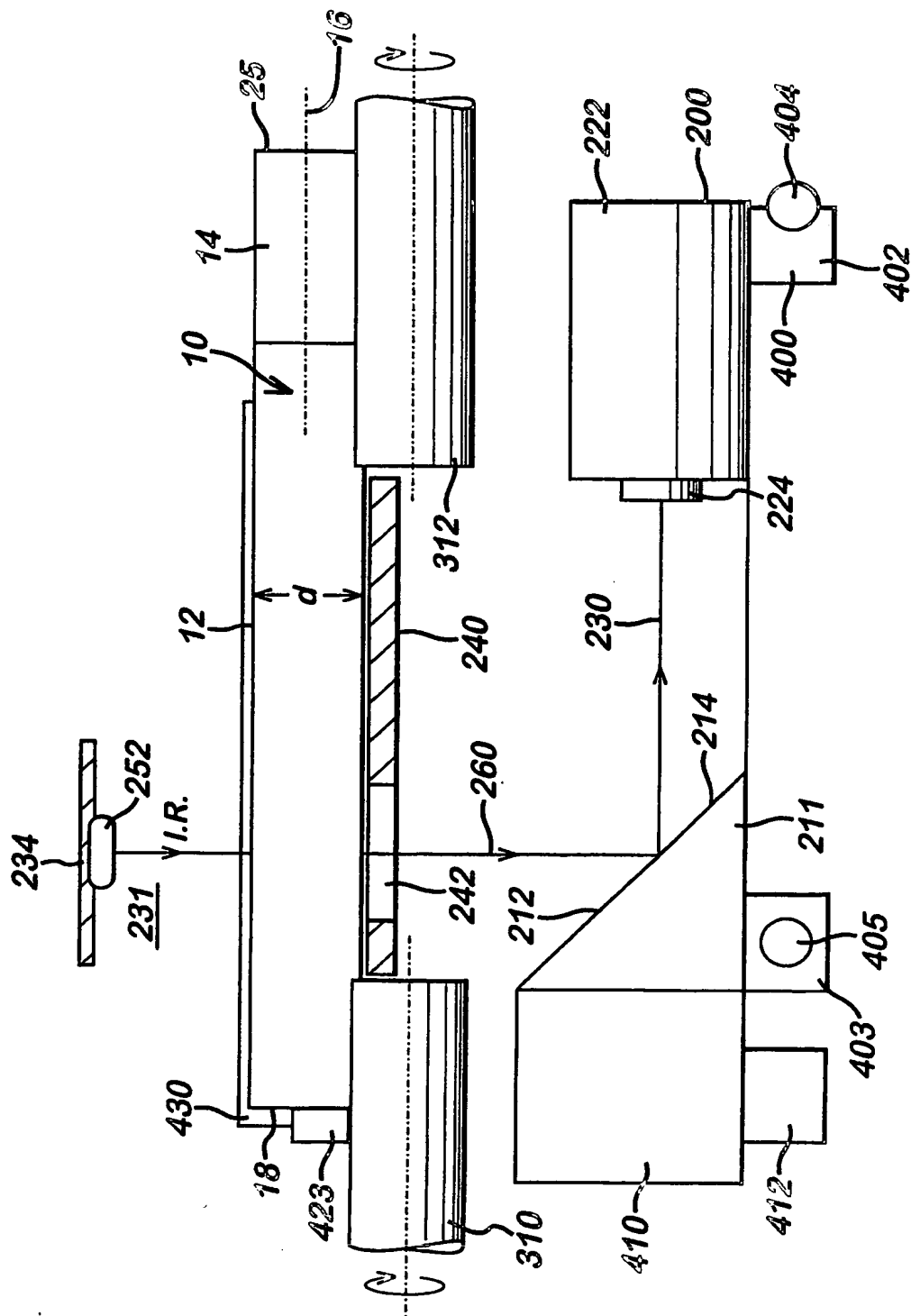
27 A reference object as claimed in claim 26, wherein said ceramic material has an alumina content of more than about 70% by weight, and more preferably more than about
15 90% or 95% by weight.

28 A reference object as claimed in claim 26 or claim 27, wherein the ceramic material comprises various other ceramic constituents, particularly magnesium oxide.

29 A reference object as claimed in any of claims 23 to 28, wherein the ceramic material comprise about 99.7% weight alumina, with the balance being substantially
20 magnesium oxide.

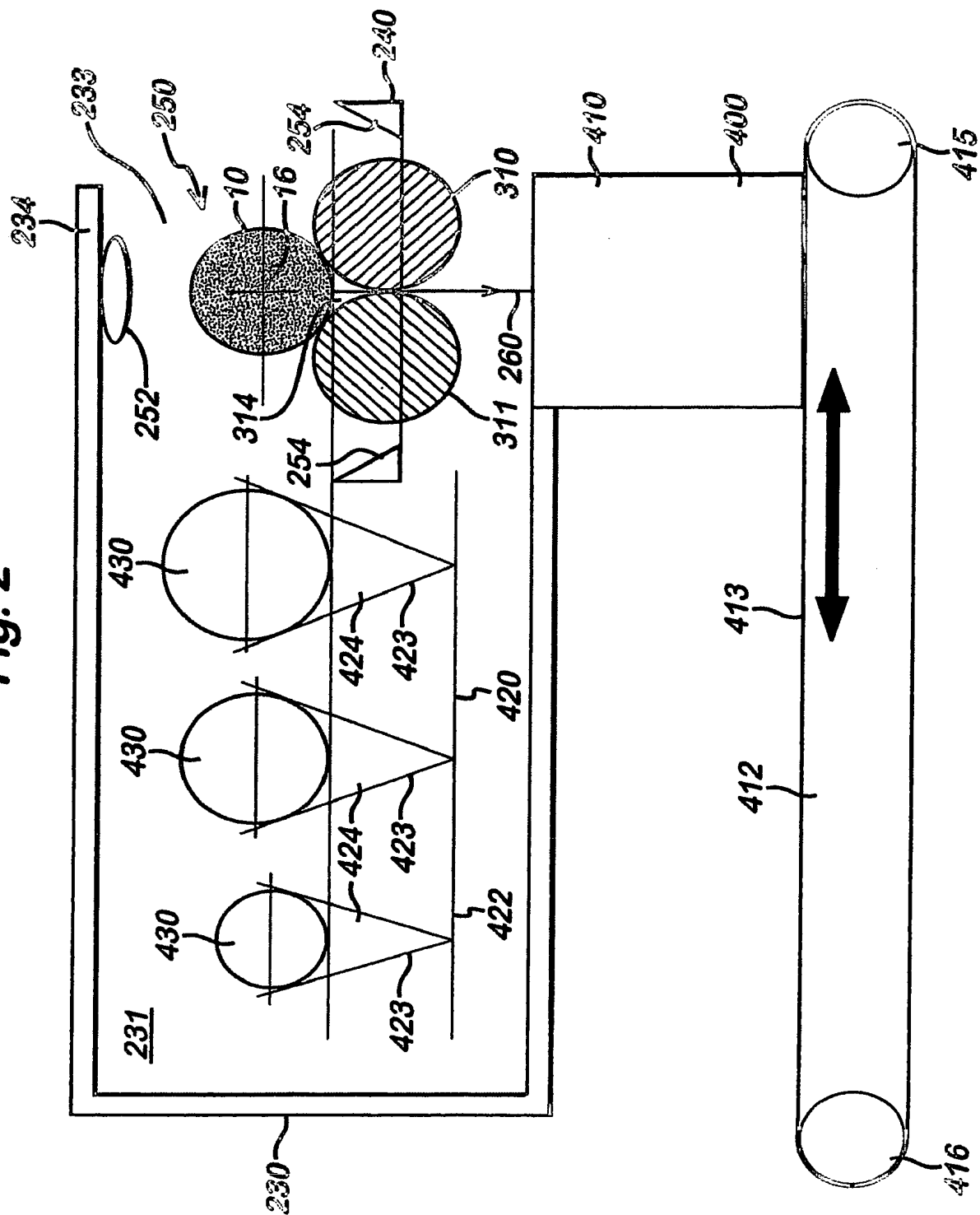
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Fig. 1

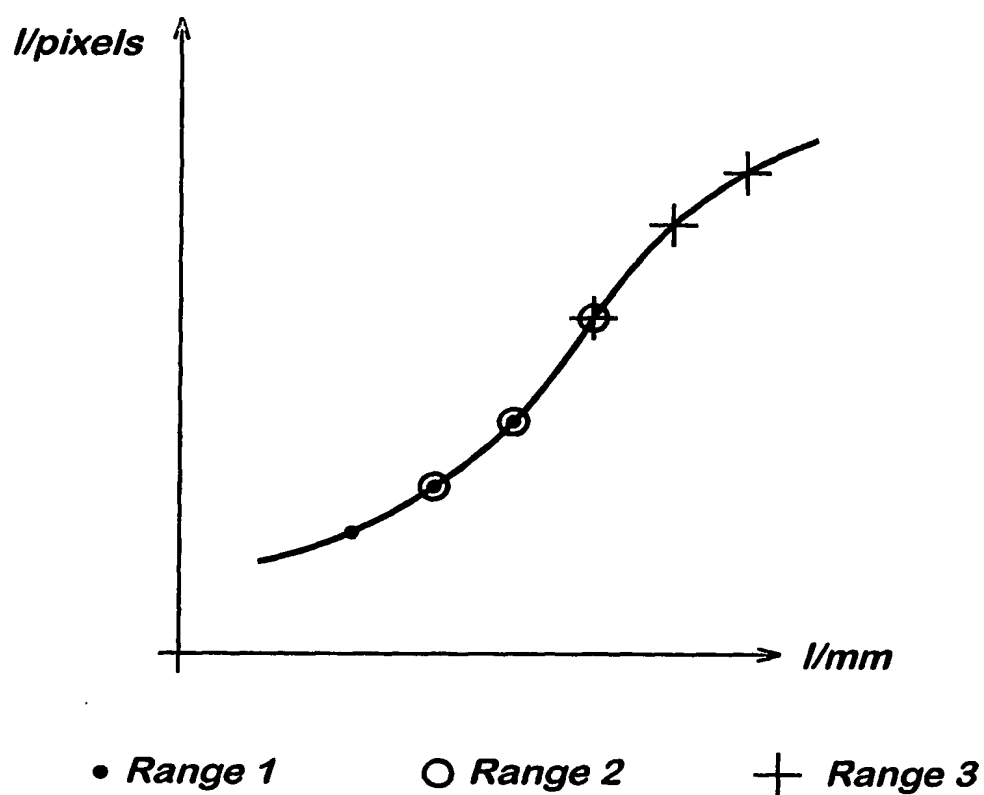


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Fig. 2



3/3

Fig. 3

INTERNATIONAL SEARCH REPORT

PCT/GB2004/001177

A. CLASSIFICATION OF SUBJECT MATTER IPC 7 A24C5/34 G01N21/93 G01B11/10 G01N21/952		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC 7 A24C G01N G01B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 758 742 A (AT & T CORP) 19 February 1997 (1997-02-19) * column 10, line 43 - column 17, line 5; column 19, line 50 - column 20, line 5; column 25, line 46 - column 26, line 8; figures 2 and 4A *	1-22
Y	EP 1 028 305 A (SCHLAFHORST & CO W) 16 August 2000 (2000-08-16)	1-10, 12-21
X	* paragraphs '0015!', '0026!'-'0029!', '0031! *	23-29
Y	FR 2 256 394 A (ARMINES) 25 July 1975 (1975-07-25) * page 6, lines 7-23; page 7, lines 11-24 *	1-6, 9-17, 20-22
<input type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex.		
* Special categories of cited documents : *A* document defining the general state of the art which is not considered to be of particular relevance *E* earlier document but published on or after the international filing date *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *O* document referring to an oral disclosure, use, exhibition or other means *P* document published prior to the international filing date but later than the priority date claimed *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. *Z* document member of the same patent family		
Date of the actual completion of the international search 6 July 2004		Date of mailing of the international search report 16/07/2004
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016		Authorized officer Hoogen, R

INTERNATIONAL SEARCH REPORT

PCT/GB2004/001177

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this International application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-22

Machine vision equipment incorporating automatic set-up means and method of setting-up said machine vision equipment

2. Claims: 23-29

Object made of a low reflectance ceramic material

INTERNATIONAL SEARCH REPORT

PCT/GB2004/001177

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